

APPLICATION

FOR

REISSUE OF

UNITED STATES LETTERS PATENT

NO. 5,662,584

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detrimental loss of image resolution. In recognition of the two-fold desire to maximize the field of view and image resolution, efforts have been made by others to provide endoscopes with a zoom lens system. Such endoscopes typically include an objective lens stage, a zoom lens stage, and a focusing lens for making certain that the image passed by the zoom lens is in focus. In the case where a solid state imaging device is used in an endoscope, the desired focus control can be achieved and maintained by shifting the solid-state imaging device along the axis of the endoscope in a direction and by an amount sufficient to achieve the desired focus control.

An example of an endoscope having a zoom lens and a movable imaging device system is disclosed by U.S. Pat. No. 4,488,039, issued 11 Dec. 1984 to Masamichi Sato et al for "Imaging System Having Vari-Focal Lens For Use In Endoscope". In essence the arrangement disclosed in U.S. Pat. No. 4,488,039 is one in which the position of the imaging device that is required to achieve proper focusing is estimated on the basis of the position of the zoom lens. However, the Sato et al endoscope is handicapped by the fact that the process of estimating is conducted "on the fly", which appears to limit the accuracy and/or response time of the system with respect to optimizing continuous focusing during movement of the zoom lens.

U.S. Pat. No. 4,488,039 suggests that the endoscope may be modified so as to make its control system capable of detecting changes in the position of the imaging device and then estimating an appropriate position for the zoom lens in order to achieve proper focusing of the sensed image on the imaging surface of the imaging device. That arrangement appears to suffer from the need to estimate the appropriate position for the zoom lens unit as the imaging device is being moved, so that the system disclosed by U.S. Pat. No. 4,488,039 does not embody a practical electrical mechanical design that is relatively inexpensive to manufacture and also is characterized by an efficient and reliable mode of operation.

The endoscope described in said copending U.S. application Ser. No. 08/319,886 embodies a zoom lens unit which is under operator control, plus a CCD imaging device which also is under operator control. As the zoom lens unit position is modified, the lens system focal plane shifts (inward or outward according to the direction of movement of the zoom lens unit) causing the image seen by the CCD imaging device to become unfocused. Also as the object of attention in the video image varies in distance from the lens system, the position of the lens system focal plane also shifts, causing the image projection seen by the CCD imaging device to become unfocused. Accordingly, the endoscope invention of said copending U.S. application Ser. No. 08/319,886, embodies an automatic control system (hereinafter described) which serves to capture a properly focused image. The automatic control system compensates for both focal plane shifts by automatically shifting the CCD imaging device position to track the lens system focal plane, and thereby maintain proper focus at the image-receiving surface of the imaging device. The control system requires as input parameters specified by the operator both the zoom lens setting and the distance from the lens system to the object of interest (the "object distance"). With that information (plus its knowledge of the characteristics of the lens system) the control system is able to maintain proper focus under all conditions. Thus, the operator may vary the zoom and deflect distance parameters over some predetermined allowable range of values, and expect the control system to properly adjust focus to track his or her commands.

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However, particularly since the range of values which may be specified for either parameter is limited, it becomes advantageous to provide some form of information feedback from the control system to the operator to indicate the parameter values currently specified by the operator and their relationship to their respective permissible ranges. It also is useful to the operator to indicate, by some form of information feedback, that a particular parameter has been driven to a limit of its permissible range and hence may not be driven further in that direction.

SUMMARY OF THE INVENTION

The primary object of this invention is to provide an endoscope of the type described with means for generating feedback information to the operator to indicate the instantaneous position(s) of the zoom lens unit and/or the imaging device. The method and means chosen for providing the feedback information utilizes the video display means (e.g., TV monitor) which is used to display the optical image seen by the endoscope's objective lens. Preferably the video display means is used to simultaneously display a representation of both the zoom and object distance (focus) parameters, and also (at selected times) the limits of said parameters.

A further object of this invention is to provide an endoscope of the type comprising a movable zoom lens unit and a movable electronic imaging device, first and second selectively operable means for moving said zoom lens unit and said imaging device respectively, and novel means for displaying the position of said zoom lens unit and/or said imaging device.

A more specific object is to provide an electronic endoscope of the type having a zoom capability with a novel means for displaying the position of the zoom lens.

Another specific object of this invention is to provide an electronic endoscope of the type having a movable solid state imaging device with a novel means for displaying the position of the solid state imaging device.

A further object is to provide an endoscope of the type having an objective lens, a zoom lens unit for varying the effective field of view of the image transmitted by said objective lens, a solid state imaging device capable of providing an output signal representative of the image it receives from said objective lens via said zoom lens unit, an electromechanical control means for selectively changing the axial position of the zoom lens unit and/or the imaging device so as to assure that the optical image formed by the zoom lens is focused on the image-receiving surface of the imaging device, electronic display means responsive to the output signal from said imaging device for generating a visual display of the image transmitted by the objective lens, and means for causing said display means to generate an indication of the positions of said zoom lens and said imaging device in relation to predetermined end limits of the paths of movement of said zoom lens unit and said imaging device.

In the preferred embodiment of the invention, the endoscope comprises a tube in which the objective lens is mounted, means supporting said zoom lens and said solid state imaging device inside of said tube, first and second motion-transmitting means for moving said zoom lens and said imaging device respectively along the axis of said tube, whereby the spacing between said zoom lens and said objective lens and also the spacing between said zoom lens and said imaging device along the axis of said tube may be changed, a handle attached to said tube, display means for

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generating a display of the image seen by said imaging device, control means including manually operable switch means carried by said handle for controlling movement of said zoom lens and said imaging device by said first and second motion transmitting means, said control means being adapted to position said zoom lens and/or said imaging device so that said imaging device is substantially at the focus of said zoom lens at each position of said zoom lens, and means coupled to said display means for generating a display indicative of the positions of said zoom lens and said imaging device as they are moved between predetermined end limits. The control means comprises means for sensing the position of said zoom lens and said imaging device along the optical axis of the endoscope, a lookup table containing information as to the spacing required to be maintained between said zoom lens and said imaging device in order for the focal plane of said zoom lens to be located substantially at the image-receiving surface of said imaging device for all positions of said zoom lens system, means for accessing the data stored in said lookup table, and means for moving said zoom lens system and/or said imaging device in response to and in accordance with the accessed data.

Other objects, advantages and novel features of the invention will become more apparent from a consideration of the following detailed description when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view, partially in section, illustrating a preferred embodiment of the invention;

FIG. 2 is a perspective view similar to FIG. 1, with certain components removed to better illustrate the construction of the device;

FIG. 3 is a view similar to FIG. 2, but with additional components removed to better illustrate the construction;

FIG. 4 is a cross-sectional view on a greatly enlarged scale taken along line 4—4 of FIG. 1;

FIG. 5 is a perspective view on an enlarged scale of certain components of the endoscope, with certain components broken away;

FIG. 6 is a fragmentary exploded view on an enlarged scale of certain components of the endoscope;

FIG. 7 is an enlarged fragmentary perspective view illustrating the drive trains for the zoom lens unit and the imaging device, with portions broken away;

FIG. 8 is a side view in elevation further illustrating the drive trains for the zoom lens unit and the imaging device;

FIG. 9 is a front end view of the endoscope illustrating the disposition of the optical fibers used to illuminate the surgical site;

FIG. 10 is a fragmentary sectional view in elevation of the elongate bushing used to support the drive rod for the imaging device;

FIG. 11 is a fragmentary sectional view on an enlarged scale illustrating how the bundle of optical fibers is terminated at the proximal end of the endoscope;

FIG. 12 is a schematic view of the electronic control console to which the endoscope of FIG. 1 is connected;

FIG. 13 is a block diagram identifying components of the control system for the endoscope, including certain components established by programming of the computer that form part of the control console;

FIG. 14 is a schematic view further illustrating the control system;

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FIG. 15 illustrates the type of curves that are recorded in a lookup table that forms part of the invention:

FIGS. 16-19 are flow diagrams illustrating the mode of operation established by the computer software program embodied and/or used with the controller of the endoscope; and

FIGS. 20-28 illustrate the means provided according to this invention for generating position marker displays.

In the several views, the thickness and/or overall size of certain components are exaggerated for convenience of illustration. Thus, for example, the thicknesses of the inner and outer tubes and the diameter of the optical fibers identified hereinafter are not to scale in FIGS. 4, 9 and 11. Also, the same elements are identified by the same numerals in the several views.

DE DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring first to FIG. 1, there is illustrated an electronic endoscope comprising a handle unit 2 and an elongate tubular assembly 4. Handle unit 2 comprises a housing 6 with openings through which four control switch buttons 8A-8D protrude. A fiber optic cable 10 and an electrical cable 12 are attached to the proximal (rear) end of housing 6. The elongate tubular assembly 4 comprises a cylindrical outer tube 14 which is open at its distal (front) end. The proximal end of tube 14 extends into housing 6 and is secured by a clamp 18 to a first portion of a mounting frame 16 (FIGS. 2 and 8). Housing 6 preferably consists of two or more mating parts that are releasably secured to one another and frame 16 by suitable screw fasteners (not shown). Mounted within outer tube 14 is a cylindrical inner tube 20 (FIGS. 4, 5 and 8) which has its distal (front) end terminating substantially in the same plane as the corresponding end of the outer tube. The proximal end of inner tube 20 extends beyond the corresponding end of outer tube 14 and is anchored by a clamp 22 (FIG. 8) to a second portion of frame 16.

As seen in FIGS. 4 and 9 the inner tube is smaller than and is mounted eccentrically to the outer tube, so as to leave a crescent shaped area to accommodate a plurality of optical fibers 28 (FIGS. 9 and 11) that are used to transmit light to illuminate the surgical site, i.e., the objective lens field of view. The distal (forward) ends of fibers 28 may (but need not) be bonded to one another by a suitable cement such as an epoxy resin; in either case, the fibers are locked in place between the two tubes, with their forward ends being optically polished and terminating substantially flush with the plane of the distal end edge of the outer tube. Fibers 28 project out of the rear end of outer tube 14 and are collected in a protective tubing 30 preferably made of a material such as a silicone rubber. The rear ends of fibers are captured in a ferrule 32 that is used to connect it to cable 10. The rear end surfaces of fibers 28 are optically polished.

Referring now to FIGS. 2, 4, 5 and 10, mounted within and locked to inner tube 20 is an elongate bushing 34 that has a sleeve bearing 36 located at each end of its central bore or lumen 35 (FIG. 10). Bearings 36 are made of a material having a low coefficient of friction. The proximal (rear) end of bushing 34 terminates substantially flush with the corresponding end of inner tube 20. The forward end of bushing 34 terminates intermediate the opposite ends of tube 20 (FIG. 5). As seen in FIG. 4, bushing 34 has a generally cylindrical outer surface 38 sized so that it makes a close or tight fit with the inner surface of inner tube 20. That generally cylindrical outer surface of the bushing is dis-

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The drive means for zoom unit 60 comprises a reversible electrical d.c. motor 106. Both it and motor 80 are attached to frame 16 by a removable clamp 82. Motor 106 is identified hereinafter as the "zoom motor". The output shaft of motor 106 carries a pinion gear 108 that meshes with a pinion gear 110 that is mounted on and secured to a shaft 112. The latter is rotatably mounted to mutually spaced portions 114, 116 of frame 16. Shaft 112 carries two axially spaced gears 120A and 120B that mesh with teeth 102 on rods 100A and 100B respectively, whereby rotation of shaft 112 by operation of motor 106 will cause linear motion of rods 100A and 100B, and thereby zoom lens unit 60, lengthwise of inner tube 20 in a direction determined by the

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Referring now to FIG. 13, the housings of focus motor 80 and zoom motor 106 include position-sensing encoders represented schematically at 120 and 122 that are coupled to the output shafts of the motors and are designed to provide pulse-type signal outputs that are polarized plus or minus according to the direction of movement of the output shafts of motors 80 and 106 respectively. Shaft encoders 120 and 122 may take various forms but preferably they are incremental digital encoders. Because incremental position-sensing shaft-coupled encoders are well known, details of construction of the encoders are not provided herein.

FIG. 12 diagrammatically illustrates an electronic console 130 to which the endoscope is coupled. Essentially the console comprises a light source 134 for the endoscope, an electronic controller comprising a digital computer 138 (which includes a microprocessor and associated memory, control and input and output circuits), a display module 140 that includes a CRT display device (FIG. 20) whereby the surgeon or other user may monitor the images seen by the endoscope, an electronic memory device 142, preferably but not necessarily in the form of an E-prom, that serves as a zoom/focus lookup table as hereinafter described, and a power supply 132 for the solid state imaging unit 50, motors 80 and 106, and the electronic controller. Power supply 132, light source 134, computer 138, display module 140 and E-prom 142 are interconnected as represented schematically in FIG. 12 so as to permit the mode of operation described hereinafter. Although not shown, it is to be understood that power supply 132 includes a manually operated main power switch (not shown) which is used to turn the instrument "on" and "off".

Optical fiber cable 10 is coupled to console 130 so as to be able to transmit light from light source 134 to light fibers 28, whereby when that light source is energized by operation of the controller, the resulting light beam will illuminate the objective field of view. Multi-wire cable 12 is connected at its outer end to power supply 132 and computer 138; at its inner end cable 12 has certain of its wires coupled by a connector (not shown) to terminals of the CCD chip of imaging device 50 and others of its wires connected to motors 80 and 106 and the control switches associated with buttons 8A-8D.

Referring again to FIG. 13, the switch buttons 8A and 8B form part of two focus control switches 144A and 144B, while switch buttons 8C and 8D form part of two zoom control switches 144C and 144D. Preferably, a second like set of foot-operated switches (not shown), are added in parallel with switches 144A-D so as to give the surgeon the option of controlling maneuvering of imaging device 50 and zoom lens unit 60 using one of his feet rather than one of his hands. As explained further hereinafter, operating switch 144A will energize focus motor 80 so as to cause the imaging device to move forward toward the distal end of inner tube 20, while operating switch button 144B will energize focus motor 80 so as to cause reverse movement of the imaging device. Similarly, operating switch button 144C will energize motor 106 so as to cause the zoom lens unit to move forward toward the distal end of inner tube 20, while

FIGS. 16-19 are flow charts illustrating some of the software program for computer 138. Some or all of the

At this point, a focus motor servo control loop (FIG. 19) is activated, which control loop provides the following operation. As the imaging device 50 is moved in a "Down" direction to its predetermined start-up position, encoder 120 will generate pulses that are accumulated in counter 162. The output of object distance counter 160, preset by the computer to the predetermined start-up value "n" and the output of zoom motor position counter 164, are applied to E-prom 142 to obtain an output from the zoom/focus lookup table that has a value representing the desired imaging device position. The output from E-prom 142 (representing the desired CCD position) and the output of CCD position counter 162 (representing the actual CCD position) are applied to comparator 174. Depending on whether the actual CCD position represented by the output of counter 162 is

At this point, if the distance between the endoscope and the viewed object ("object distance") is at the value for which the imaging device and the zoom unit are preset as a result of the reset routine, the image that is displayed by display device 140 will be in focus. Subsequently, if the object distance changes, e.g., as a result of the endoscope being moved, or the surgeon's point of interest is changed, the displayed image may go out of focus. In such event, the surgeon can reacquire a sharp focus by operating one or the other of buttons 8A and 8B. The resulting operation will cause counter 160 to be either increased or decreased by clocked pulses while switch 8A or 8B respectively is depressed. This changed value in counter 160 is applied to the zoom/focus lookup table, resulting in a new output value being transferred from the lookup table to comparator 174. The result is a change in the error signal output from comparator 174, which in turn is utilized by the servo control system to further operate motor 80 until the adjusted CCD position as measured by counter 162 again results in a zero error signal.

Once sharp focusing has been achieved, the image will remain in focus on the image-receiving surface of the CCD imaging device even though the operator utilizes buttons 8C or 8D to operate the zoom motor so as to zoom up or down with regard to the object being viewed. As seen in FIG. 17, the zoom motor encoder 122 tracks zoom motor position, and the output of the zoom motor encoder is used to drive the E-prom to a new output value. The new value obtained from E-prom 142 is compared with the signal output of counter 162 to modify the error signal. That error signal is then utilized in the servo-control loop to cause the focus motor to operate in a direction and for a duration sufficient to locate the CCD imaging device at a position which assures that sharp focusing of the image is achieved despite the change in field of view caused by zooming up or down.

It is to be appreciated that when its main power switch (not shown) is turned on and/or the reset switch is actuated, the control system described above will automatically set the imaging device 50 and the zoom lens unit to a preselected position which provides a predetermined field of view with sharp focusing at the CCD device of the image seen by the objective lens. Thereafter, the operator has the advantage that by depressing either of the buttons 8C and 8D, the field of view may be changed without changing the object distance between the objective lens and the object being viewed. Additionally, if the need arises to change the posi-

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tion of the endoscope so as to change the object distance, the operator has the option of utilizing buttons 8A and 8B to refocus the image, and also the option of utilizing buttons 8C and 8D to change the field of view without again having to utilize the buttons 8A and 8B to change the position of the imaging device in a direction to restore or maintain a sharp image for viewing on displaying device 140.

FIG. 20 generally illustrates in diagrammatic form a system for providing an electronically generated display of the optical image that is passed by the objective lens unit 48 and zoom lens unit 60 to imaging device 50. An endoscope video signal derived from imaging device 50 is processed by conventional video circuits identified generally at 200 to provide signals that are applied to a TV monitor 204 so as to cause the latter to reproduce as a TV image the optical image seen by the endoscope's objective lens unit. The video circuits 200 and the circuits hereinafter described are preferably embodied in display module 140 (FIG. 12). The signal processing video circuits may take various forms known to persons skilled in the art and do not constitute part of the present invention. Suffice it to say that the optical image is reproduced with a magnification and field of view determined by the position of the zoom lens unit and a focusing accuracy determined by the position of imaging device 50 along the endoscope's optical axis.

Turning now to FIGS. 21 to 28, the present invention involves provision of means for generating video image markers ("indicators") that provide the surgeon with an indication of the instantaneous zoom and focus settings as well as the maximum and minimum zoom and focus settings. When focus control button 8A or 8B is operated, two vertically spaced rectangles are created on the TV monitor screen, one representing the instantaneous setting of the imaging device (focus display) and the other representing the instantaneous setting of the zoom lens unit (zoom display). The same markers are displayed if either of the zoom control buttons 8C and 8D are depressed. For convenience, these rectangular markers representing instantaneous settings are identified as "bar-graph displays" in recognition of the fact that they move horizontally in synchronism with movement of the imaging device and the zoom lens unit so that their horizontal positions provide an indication of the instantaneous positions of the imaging device and the zoom lens unit. Additionally, as the imaging device and the zoom lens unit approach either of their end limits of travel, i.e. their maximum or minimum limits, the display control system additionally generates a limit position marker in the form of an additional rectangular display. The instantaneous rectangular position display markers are displayed only when one of the control buttons 8A-8D is operated and for a brief period after the button has been released, and a maximum or minimum limit marker is generated only as the imaging device or the zoom lens unit, as the case may be, approaches its maximum or minimum limit position respectively. The maximum and minimum limit markers are extinguished at the same time as the instantaneous position markers.

As represented in FIG. 21, the system for generating and controlling the position and limit marker displays comprises a video sync stripper circuit 206 which recovers or develops from the endoscope video signal output of imaging device 50 a vertical sync signal (V-Sync), a horizontal sync signal (H-Sync), and also a clock signal identified hereinafter as a "pixel clock". Those signals are applied as input signals to marker display control circuits, identified generally by numeral 210 which include inter alia, a pixel counter 212, a line counter 214, and pixel and line comparators 216 and

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The output of pixel counter 212 is applied to three different comparators 216A, 216B, and 216C. Comparator

FIG. 26 illustrates how the system also is designed to produce two control signals identified as "Enable Focus Indicator Display" and "Enable Zoom Indicator Display". The means for producing these control signals comprises a bar-graph pixel counter 250, two comparators 252 and 254, and a multiplexer 256. The bar-graph pixel counter 250 is clocked by the pixel clock pulses derived from the endoscope video signal. Predetermined initial minimum values for zoom and focus are applied sequentially to the bar-graph pixel counter according to the line count. This is accomplished by applying predetermined object distance minimum value signals and zoom minimum value signals inputs to multiplexer 256, with the latter being controlled by application of the "Enable Focus Display" signal and the "Enable Zoom Display" signal produced by line comparators 218A and 218B, respectively. When the line counter has a value in the range of 32-40, multiplexer 256 is switched by the "Enable Focus Display" signal so as to pass the predetermined object distance minimum value signal to bar-graph pixel counter 250, thereby causing the latter to be preset to the minimum object distance value. When the line count is 232-240, multiplexer 256 is switched by the "Enable Zoom Display" signal so as to pass the predetermined zoom initial minimum value signal to counter 250 so as to preset the counter to that minimum value.

Comparators 252 and 254 also receive the outputs of object distance counter 160 and zoom position counter 164. When the output from object distance counter 160 matches the output of bar-graph pixel counter 250, comparator 252 will produce the "Enable Focus Indicator Display" signal. The "Enable Zoom Indicator Display" signal is generated when the signal from zoom counter 164 matches the value of the output of bar-graph pixel counter 250.

As shown in FIGS. 27A to 27F, the invention further comprises six "AND" gate output circuits that cause the several indicators (markers) to be displayed on the monitor screen. For this preferred embodiment each output AND gate circuit generates an "Insert Video White" signal that is applied to video monitor 204 so as to cause the latter to display a white marker on its screen.

FIGS. 27A and 27B show AND gate circuits for causing the focus and zoom position markers to be generated. In FIG. 27A, AND gate 260 generates an "Insert Video White" signal for producing the focus position marker in response to the "Enable Focus Display", "The Enable Bar Graph Display" and the "Enable Focus Indicator Display" signal; also, in response to the "Enable Display For One Second" signal, it maintains that insert video white signal for an additional second after the focus control button that was depressed has been released. In FIG. 27B, the AND gate 264 generates an "Insert Video White" signal in response to the "Enable Zoom Display", "Enable Bar Graph Display" and the "Enable Zoom Indicator Display" signal and again, in response to the "Enable Display For One Second" signal, it also maintains that insert white signal for an additional second after the depressed zoom button has been released.

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